Effectiveness in cleaning oval-shaped root canals using Anatomic Endodontic Technology, ProFile and manual instrumentation: a scanning electron microscopic study

O. Zmener[1], C. H. Pameijer[2] & G. Banegas[1]

[1]Department of Adult Dental Care, Section of Endodontics, Faculty of Odontology University of Buenos Aires, Buenos Aires, Argentina and [2]University of Connecticut School of Dental Medicine, Farmington Ave, CT, USA

Abstract

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Aim To compare *in vitro* the cleanliness of root canal walls in oval-shaped root canals following automated or manual instrumentation.

Methodology Forty-five oval-shaped single-rooted maxillary and mandibular premolars with straight canals were divided into three groups of 15. Automated canal preparation was performed using Anatomic Endodontic Technology (AET, group 1) and the ProFile system (group 2). Manual instrumentation (group 3) was performed with K-Flexofiles. Irrigation was performed using alternately 5.25% NaOCl and 17% EDTA, followed by rinsing with saline. The roots were split longitudinally into halves and the canals examined at ×200 and ×400 in a scanning electron microscope. The presence of debris and smear layer was recorded at distances of 1, 5 and 10 mm from the working length using a three-step scoring scale and a 300 μm square grid. Mean scores for debris and smear layer were calculated and statistically analysed for significance ($P < 0.05$) between and within groups, using the Kruskal–Wallis nonparametric ANOVA and Dunn's tests.

Results At 1, 5 and 10-mm levels the root canals prepared with AET had significantly less surface debris and smear layer on the canal walls compared with canals prepared with ProFile or manual instrumentation. For all three groups significantly lower mean smear layer scores ($P < 0.05$) were recorded at 5 and 10-mm levels compared with the 1 mm level. Significantly lower mean debris scores ($P < 0.05$) were also recorded at 5 and 10-mm levels for the AET group whereas no significant differences were found between the three levels for the ProFile and manual instrumentation groups.

Conclusions Although better instrumentation scores were obtained in canals prepared with AET, complete cleanliness was not achieved by any of the techniques and instruments investigated.

Keywords: Anatomic Endodontic Technology, cleaning efficacy, EDTA, endodontics, K-Flexofiles, oval canals, ProFile, root canal instrumentation, scanning electron microscopy, sodium hypochlorite.

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Introduction

Thorough debridement of the root canal system is considered one of the most important steps in root canal treatment. The main objective of biomechanical instrumentation is the total elimination of infected pulp tissue from the root canal (Smith *et al.* 1993, European Society of Endodontology 1994). In addition, pulpal remnants, debris and a smear layer produced by instrumentation of the root canal walls must be totally removed (Cergneux *et al.* 1987, Gettleman *et al.* 1991). Nevertheless, controversy still persists (Pashley *et al.* 1981, Madison & Krell 1984). For instance, it has been suggested that the presence of a smear layer may

Correspondence: Cornelis H. Pameijer, DMD, PhD, 10 Highwood Simsbury, CT 06070, USA (Tel.: +1 860 651 8228; fax: +1 860 651 7427; e-mail: phpameijer@comcast.net).

prevent bacterial penetration into the underlying dentinal tubules (Pashley *et al.* 1981). On the contrary, the presence of an infected smear layer may prevent antimicrobial agents from gaining access to the infected dentinal tubules (Shovelton 1964). Furthermore, the removal of the smear layer may enhance the adaptation of obturation materials to the root canal walls (Cergneux *et al.* 1987, Gettleman *et al.* 1991, Economides *et al.* 1999).

Depending on differences in anatomy the degree of cleanliness of the root canal may vary. Wu & Wesselink (2001) determined that it may be difficult to instrument the entire wall in teeth with oval-shaped canals and that un-instrumented recesses may remain. The introduction of engine-driven nickel-titanium rotary instruments such as ProFile .04 and .06 taper instruments minimize the incidence of potential procedural errors that frequently occur during root canal instrumentation (Greene & Krell 1990). ProFile instruments produced better centred preparations and larger sized apical stops (Bryant *et al.* 1998a,b, Kavanagh & Lumley 1998). However, a considerable amount of residual debris and smear layer was frequently detected on root canal walls after canal preparation (Peters & Barbakow 2000, Ahlquist *et al.* 2001).

Recently, an innovative concept of mechanical root canal preparation, the Anatomic Endodontic Technology (AET) has been introduced (White 2002). AET was specifically designed to maintain the natural shape of the root canal during preparation. The manufacturer claims that this system is intended to minimize the number of steps and instruments required for effective preparation of root canals. The system is composed of a new generation of flexible stainless-steel instruments, a series of disposable syringes and 30-gauge needle tips. For canal preparation, two different types of instruments are employed. The Shaping files are used to prepare the bulk of the root canal to within 3–4 mm of the working length. They are designed to be used in a 30° reciprocating 4 : 1 low-speed handpiece and to be guided by the anatomical shape of the canal, cutting with their fins in a milling-type action. Their flexible ends theoretically do not cut at the tip, thus preventing ledging. The Apical files, which cut only at the tips, are designed to be used manually and prepare the apical area of the canal. To date, there is no information available on the root canal cleanliness in oval-shaped root canals after preparation with AET.

The aim of this study was to compare by means of scanning electron microscopy, the presence of a smear layer and remnants of debris on the walls of oval-shaped root canals after preparation with AET, ProFile .04 and .06 taper rotary instruments and manual instrumentation.

Materials and methods

Forty-five freshly extracted single-rooted maxillary and mandibular premolars, each with one single oval-shaped root canal were used. Single, oval root canal morphology was confirmed by means of radiographs made in a bucco-lingual and mesio-distal direction. Canals were determined oval-shaped if the bucco-lingual to mesio-distal dimensions had a ratio of at least 1.3–1. After extraction, the teeth were cleaned of soft tissues and hard aggregations and stored in a 0.1% thymol solution. After preparation of the access opening, gross pulpal tissue was removed with broaches. Size 10 K-files were introduced to length in the canal space and radiographs were exposed from the bucco-lingual and mesio-distal aspects of the tooth. The working length was established by deducting 1 mm from the length recorded when the tip of the file was visible at the apex when viewed at a magnification of ×2.5. Fifteen teeth were randomly allocated to one of three groups. If anatomical variations such as flaring of the root canal were present, it was assigned in an arbitrary fashion to one of the three groups. After the teeth were mounted on a holder simulating intra-oral conditions, a single operator prepared the specimens using the instrumentation technique designated for each group.

In group 1, the canals were prepared using the AET (Ultradent Products Inc., South Jordan, UT, USA) according to the manufacturer's instructions. The operative procedures were as follows. The coronal two-thirds were enlarged with Shaping files 1, 2 and 3. Initially, a size 1 shaping file (2.5% taper) was inserted by hand to approximately 4 mm short of the established working length. The file was then used in a reciprocating 4 : 1 low-speed hand piece and the canal was instrumented to the same length at ±250 rpm and a side-to-side/up-and-down motion. Intermittently, three to four times, the file was used in a slight lifting motion whilst stroking, to facilitate outward removal of debris. With each stroke, the file was reinserted exerting a buccal to lingual cutting pressure on the outstroke. In teeth in which the mesial and distal aspects provided no resistance, the file was lightly wiped against these walls for a few seconds. During the reciprocating motion, the canals were constantly flushed with saline from an internal water spray

provided by the hand piece. The size 1 shaping file was used until resistance was no longer felt. The same procedures were then repeated for Shaping files 2 (4.5% taper) and 3 (6.0% taper). The size 1 shaping file was reinserted by hand to approximately 2 mm from the working length with a quarter turn twist/pull filing motion. Then, the 1, 2 and 3 Shaping files were used in the reciprocating handpiece with in-and-out movements to clean and shape the root canal to approximately 2 mm from the working length. As transition from shaping file size 1–3 provides an increased file diameter accompanied with an increase in rigidity, the instrumentation sequence was at times slightly modified depending on the difficulty of the canal to be instrumented. In other words, depending on the resistance that was experienced, a repeat of the previous file diameter was sometimes necessary. For final preparation of the canals, the Apical files 1, 2 and 3, which only cut in the apical area and have a 2.5% taper, were then used by hand to the working length with a step-back technique. Files were changed to the next size when no resistance was felt. Preparation of the apical third of the canals was judged complete when the size 3 Apical file (equivalent to a size 30 K-file at the tip) could be inserted to the working length without force.

In group 2, the canals were prepared in a crowndown manner with ProFile (Dentsply Maillefer, Ballaigues, Switzerland) instruments without exerting lingual and buccal pressure. The instruments were used according to the manufacturer's instructions. Orifice Shapers size 3, 2 and 1 were used sequentially to flare the coronal and middle thirds. ProFile .04 and .06 tapers were then used in the following sequence: 25 .06, 20 .06, and 25 .04 and introduced two-thirds to three-quarters down the canal using light apical pressure at a rotary speed of ±250 rpm using a high torque motor (Nouvag AG, Goldach, Switzerland). Each instrument was withdrawn when resistance was felt followed by the next instrument. For apical preparation, ProFile 20 .04, 25 .04, 20 .06, 25 .06, 30 .04 were sequentially used. Final shaping to the working length was achieved with a ProFile 30. 06. Instrumentation of the apical third of the canals was considered complete when the size 30 .06 ProFile instrument passed to the working length without force. When an instrument failed to go to length, the previous one was used again.

In group 3, the canals were prepared with manual instrumentation, using a step-back technique. The coronal and middle thirds were flared with Gates-Glidden instruments and the apical third was prepared subsequently with sizes 15, 20, 25 and 30 K-files (Dentsply Maillefer) to the full working length. Files were used with in-and-out movements in a circumferential manner. Preparation of the apical third was considered complete when a size 30 file could be inserted without force to the working length. Then, K-files from sizes 35–60, each size 1 mm short of the preceding instrument, were used for final preparation of the coronal and middle third. The patency of the apical foramen was confirmed with a size 10 K-file. In all groups, individual instruments were discarded after use in each root canal and irrigation was performed after each change of instrument using 2.0 mL of a 5.25% NaOCl solution followed by 2.0 mL of a 17% EDTA solution and a final rinse with 2.0 mL saline. During instrumentation, the canals were flushed with the irrigation solutions using disposable syringes and 30-gauge needles, which were placed to approximately 3–4 mm from the working length without binding. Upon completion of instrumentation the needles could be placed to approximately 2–3 mm from the working length and the root was finally flushed for 1 min with 2.0 mL of 17% EDTA solution, which was washed with 2.0 mL of 5.25% NaOCl solution followed by copious rinsing with 4.0 mL saline. Finally the canals were dried with paper points. After preparation, the specimens were stored in 100% relative humidity at 37 °C until further use. A groove was prepared on the buccal and lingual surface of the tooth; the sample was then immersed in liquid nitrogen and split longitudinally with a mallet and chisel. Teeth showing evidence that the groove had penetrated into the root canal or exhibiting an irregular cleavage were discarded and replaced with a new specimen. The paired halves of each tooth were coded and mounted side by side on an aluminium stub, coated with 200 Å of gold-palladium and examined in a scanning electron microscope (JEOL JSM-25S, Tokyo, Japan). Serial scanning electron photomicrographs were made at ×200 and ×400 magnification covering the total circumference of the canal walls at levels 1, 5 and 10 mm from the working length. For each magnification at one of the three levels of observation these photomicrographs were aligned in such a manner that they generated a horizontal panoramic view. These were then evaluated using a slight modification of a method described by Mayer *et al.* (2002). A 300 μm square grid was superimposed on the photomicrographs and a determination was made of the presence of remnants of debris and of the smear layer. Each square was considered an assessment unit and the height of the examination distance was set

at 600 μm. For evaluation purposes, all assessment units from the total area at each of the predetermined levels were analysed. When un-instrumented areas were observed they were excluded from evaluation. The amount of debris and smear layer detected at ×400 in each assessment unit was evaluated using a three-step scale. An independent operator who was unaware of the treatment the sample had received performed the scoring. Dentine chips, pulp remnants, larger particles and aggregates appearing haphazardly on the root canal walls were classified as debris. A surface film consisting of remnants of dentine and pulp tissues, with a smeared structured appearance was defined as smear layer. A score 1 was assigned when no debris or isolated small particles (±40 μm) were present. Score 2 indicated that debris covered more than 50% of the canal walls and a score 3 indicated that debris almost entirely covered the canal walls. The amounts of smear layer were graded as follows. A score 1 was assigned when all dentinal tubules were open and no smear layer was present; a score 2 indicated that some dentinal tubules were open and the rest was covered by a smear layer; and a score 3 was assigned when a continuous smear layer covered the canal walls and no dentinal tubules were seen. The average scores for each strip were calculated by dividing the sum of all individual scores by the number of evaluation units. Mean scores for debris and smear layer were finally calculated for each tooth and then each group and statistically analysed for significance ($P < 0.05$) between and within groups, using the Kruskal–Wallis nonparametric ANOVA and Dunn's tests.

Results

At ×200 magnification the instrumented canal walls from all groups appeared smooth and exhibited varying amounts of remaining debris and smear layer along the entire length of the root canal. At a magnification of ×400 smooth instrumented dentinal walls were seen which were often partially or totally free of surface debris and/or smear layer with many open dentinal tubules (Figs 1–3). Furthermore, grooves were frequently observed, especially in specimens prepared with manual instrumentation (group 3). The mean scores of debris and smear layer recorded at 1, 5 and 10 mm from the working length are shown in Tables 1 and 2, respectively. It was observed that at the 5 and 10-mm levels for all groups the canal walls were cleaner than at the 1 mm level. However, completely clean root canals were not observed in any group. At

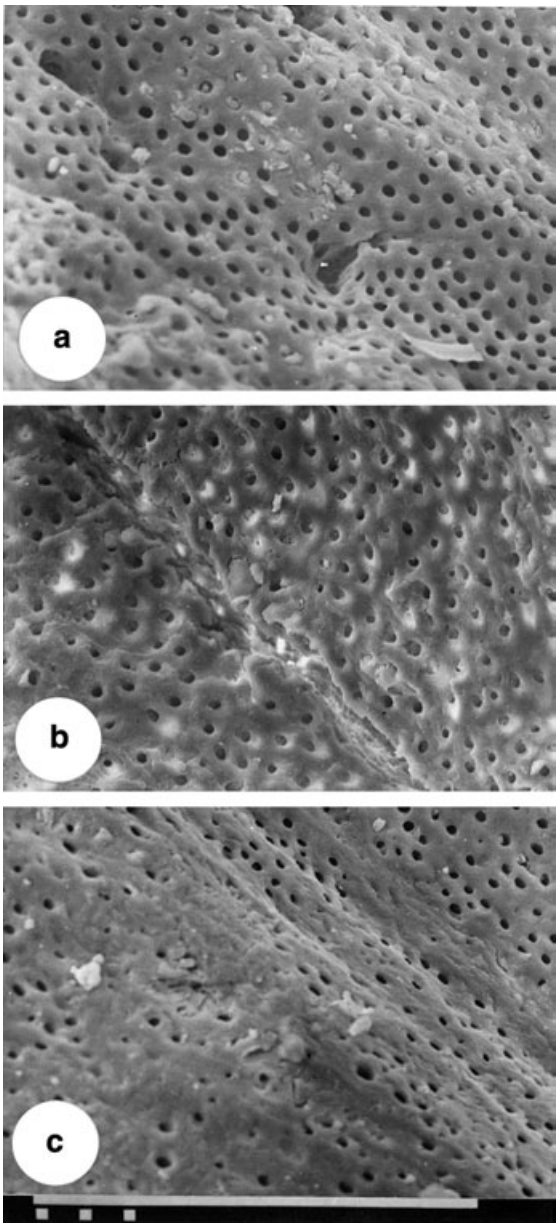

Figure 1 SEM photomicrograph of a representative specimen from group 1. (a) At the 10-mm level, the canal wall is free of debris and smear layer. Note the presence of numerous open tubule orifices (original magnification ×400). (b) At the 5-mm level, a thin coat of smear layer and numerous partially closed dentinal tubules can be seen. Note also the presence of some scattered open tubules (original magnification ×400). (c) At the 1-mm level, the canal wall is partially covered by smear layer and only a few open dentinal tubules are visible (scale bar = 100 μm; original magnification ×400).

the 1, 5 and 10-mm levels, the root canals prepared with AET had significantly less surface debris and smear layer ($P < 0.05$) than the ProFile or manual

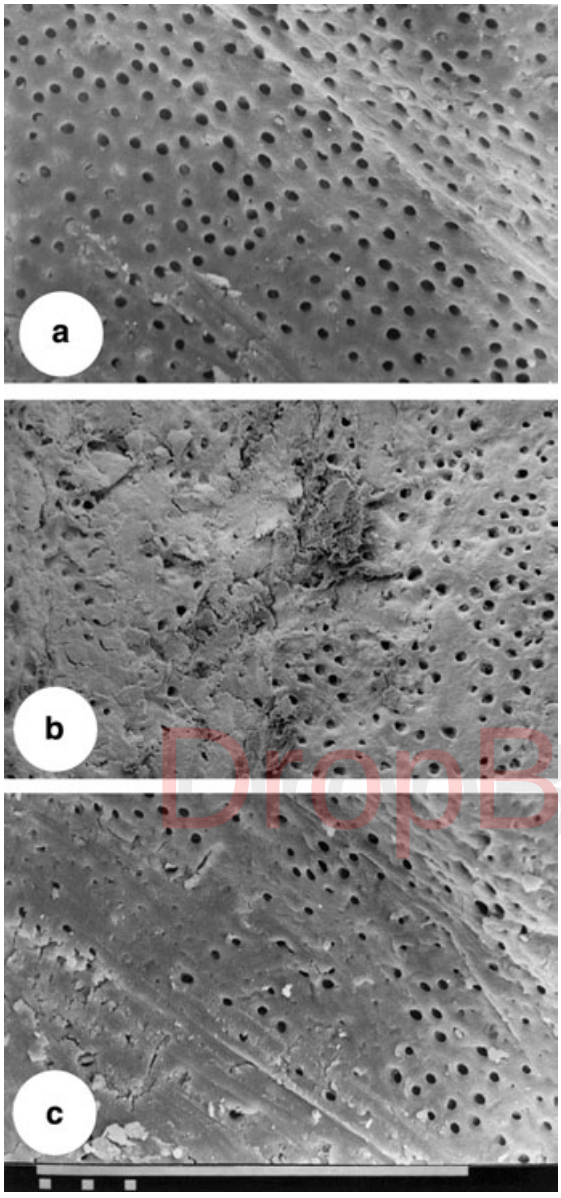

Figure 2 SEM photomicrograph of a representative specimen from group 2. (a) At the 10-mm level, numerous dentinal tubules are open whilst some small areas are covered by a thin smear layer (original magnification ×400). (b) At the 5-mm level, a thick smear layer area which obscured dentinal tubules are indicative that part of the canal wall remained untouched by instrumentation (original magnification ×400). (c) At the 1-mm level, the canal wall is partially covered by smear layer and only a few scattered open tubules can be seen (scale bar = 100 μm; original magnification ×400).

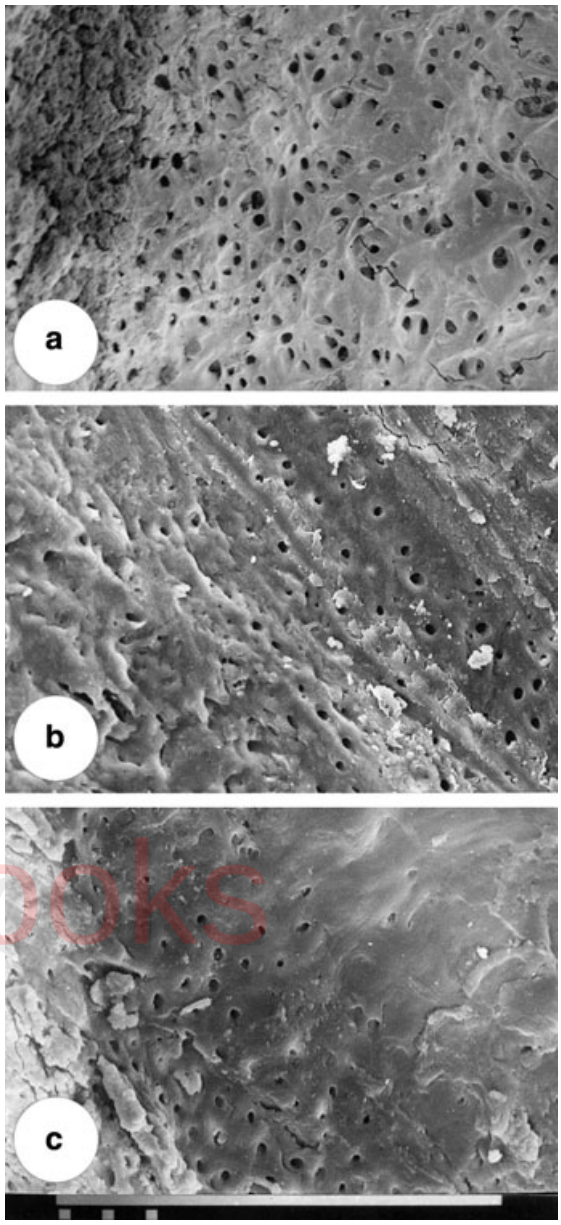

Figure 3 SEM photomicrograph of a representative specimen from group 3. (a) At the 10-mm level a thick smear layer and scattered open tubules are seen. Note the presence of remaining debris (top left) (original magnification ×400). (b) At the 5-mm level, the canal wall is covered by a thick smear layer containing partially or totally closed dentinal tubules. Here too remaining debris is present and only a few open tubule orifices can be seen (original magnification ×400). (c) At the 1-mm level, some remaining debris is still present. The canal wall is almost totally covered by a thick smear layer containing a few partially closed dentinal tubules (scale bar = 100 μm; original magnification ×400).

Table 1 Mean (SD) scores of debris removal

Group	*n*	1 mm	5 mm	10 mm
1. AET	15	1.65 (0.20)	1.42 (0.40)	1.33 (0.22)
2. PF	15	1.83 (0.44)	2.00 (0.41)	1.62 (0.33)
3. MI	15	2.03 (0.36)	2.33 (0.38)	1.64 (0.35)

Table 2 Mean (SD) scores of smear layer removal

Group	*n*	1 mm	5 mm	10 mm
1. AET	15	2.30 (0.34)	1.27 (0.35)	1.17 (0.34)
2. PF	15	2.71 (0.27)	1.84 (0.16)	1.43 (0.42)
3. MI	15	2.91 (0.11)	1.71 (0.21)	1.61 (0.31)

instrumentation samples. All groups demonstrated significantly lower mean smear layer scores ($P < 0.05$) at the 5 and 10-mm levels compared with the 1-mm level. In addition, significantly lower mean debris scores ($P < 0.05$) were recorded at the 5 and 10-mm levels compared with the 1-mm level for the AET group whereas no significant differences ($P > 0.05$) were found between the three levels for ProFile and manual instrumentation prepared canals.

Discussion

In this study a comparison was made of the cleanliness of oval-shaped root canals after preparation with two automated devices and a manual instrumentation method using a step-back technique and K-files. It has been shown by several investigators that neither instruments nor instrumentation techniques in canal preparation achieve complete cleanliness of root canal walls (Peters & Barbakow 2000, Ahlquist *et al.* 2001). The results corroborated these findings in that none of the devices and/or techniques employed in this study was completely successful in cleaning the walls of the root canals. Different methodologies using SEM have been used to score debris and the smear layer after instrumentation (Peters & Barbakow 2000, Schafer & Zapke 2000, Ahlquist *et al.* 2001, Mayer *et al.* 2002). SEM offers high-resolution images and allows the observation of areas covered by debris and/or smear layer as well as the identification of patent dentinal tubules.

In previous studies, different magnifications ranging from ×15 to ×2500 were used (Heard & Walton 1997, O'Connell *et al.* 2000, Peters & Barbakow 2000, Schafer & Zapke 2000, Ahlquist *et al.* 2001). At low magnification large amounts of debris can easily be seen, but details such as remnants of the smear layer or identification of dentinal tubules need to be observed at higher magnifications. A disadvantage of using higher magnification is the small size of the area of evaluation, potentially leading to misinterpretation. In this study a 300 μm square grid was superimposed over the micrographs that were taken at a magnification of ×400 evaluating the total circumference of the root canal at a predetermined distance from the apex. The number of micrographs required to fully sequence the circumference of the canals varied for each level. Yet this method allowed for a more accurate evaluation of remnants of debris and/or smear layer as well as the identification of patent dentinal tubules within a representative area. No assessment as to the presence of smear layer or debris was made in areas that were not instrumented. At the 1 mm level, the smear layer covered the root canal walls in the majority of the specimens for all groups and only a few dentinal tubule orifices were discernable. This was probably due to the fact that during instrumentation the tip of the needle could not be placed closer than 3–4 mm from the working length. It has been demonstrated that there is little flushing action beyond the tip of a needle, unless it is binding to the walls of the root canal and the irrigating solution is forcibly expressed (Chow 1983). In the current study, the needle was placed as deep as possible without binding, as this can be dangerous in a clinical situation (Kaufman 1981). Deeper placement of the needle slowly improved as the instrumentation progressed, however, this only occurred during final flushing and after complete preparation of the apical third of the canals. Overall, however, at the 1 and 5 mm levels, the canals prepared with AET appeared to have less surface contamination compared with using ProFile or manual instrumentation.

Our results are in agreement with previous observations (Peters & Barbakow 2000, Schafer & Zapke 2000, Ahlquist *et al.* 2001) in that the use of ProFile was less efficient in completely cleaning the root canal, leaving many areas untouched by the instruments, especially at 5 and 10-mm levels. This may be explained in that, the design of ProFile as well as other nickel titanium rotary instruments is not suitable for exertion of lateral pressure. When viewed in cross sections, ProFile tends to form round preparations in most oval-shaped canals (Short *et al.* 1997). This was confirmed in the present study in which maxillary and mandibular premolars were used. As reported previously (Wu & Wesselink 2001), the long diameter of oval-shaped canals is more frequently seen at 5 and 10-mm distance from the apex, which logically would indicate that these areas

are more prone to be out of reach of the ProFile rotary instruments. However, some isolated areas of unprepared root canal walls were also present in the AET and manual instrumentation groups.

There are several reasons that may explain why AET-shaped root canals have lower debris and smear layer scores than canals shaped by means of ProFile or manual instrumentation. The AET technique was performed with stainless steel instruments used in a 30° reciprocating side-to-side and up-and-down motion. These instruments are stiffer than nickel-titanium rotary instruments and can be easier and with less risk forced towards the root canal walls and the polar recesses during the side-to-side lifting motion. The use of stainless steel instruments in this motion was probably more efficient in following the natural shape of the oval-shaped canals and removing tooth structure. This also yielded a larger preparation with an increased volume of irrigants in direct contact with the root canal walls. In contrast, nickel-titanium instruments used only in a rotary motion and without lingual and buccal pressure, tend to partially remove tooth structure leaving untouched areas on the opposite walls. As has previously been demonstrated (Felt *et al.* 1982), the cutting efficiency and the ability to clean root canal walls is dependent on the inherent design of the instrument and the dynamics used during instrumentation. In this respect, there were often differences amongst the manufacturing characteristics of the instruments tested. As non-square cross-sectional instruments are generally more efficient than their square counterparts (Felt *et al.* 1982), it was expected that ProFile rotary instruments with their U-shaped cross-section configuration along with their radial lands on the cutting edges, would perform better than AET or hand instruments, which are square in cross section. Why this did not occur in the current study cannot be determined with certainty, although one might speculate that the better performance of the AET instruments may be related to the flute design and the sharpness of the cutting edges. Another explanation for the reduced efficiency of the ProFile rotary instruments may be the flat configuration of the outer edges, which may be responsible for packing debris further into dentinal tubules, thus making it more difficult to remove. These explanations are supported by previous findings. Felt *et al.* (1982) demonstrated that the flute design can be more important for cutting efficiency than the cross-sectional configuration. Concerning the efficacy of manual instrumentation, the results suggest that although a step-back technique was used for root canal preparation, the files when used in a circumferential motion were not totally effective in cleaning the root canal walls at the 1, 5 and 10-mm levels. This can be explained in that it is possible that the file was not sufficiently forced towards the buccal and lingual recesses, thus leaving areas un-instrumented as well as debris and smear layer behind.

Clearly, there is a need to determine the importance of these variables in another study. Another important fact that needs to be emphasized is that efficient cleaning does not necessarily depend only on the type of instrument or instrumentation technique used. In order to dissolve debris and smear layer, chemical irrigation solutions are recommended along with mechanical instrumentation (Hülsmann *et al.* 1997, Peters & Barbakow 2000, Mayer *et al.* 2002). Baumgartner & Mader (1987) found that alternating solutions of EDTA with NaOCl was the most effective combination to produce clean root canal walls. Their study demonstrated the importance of using a chelating agent such as EDTA in combination with NaOCl, to effectively remove the inorganic and organic components of the smear layer. Therefore, in this study 2.0 mL of 5.25% NaOCl and 2.0 mL of 17% EDTA was used in an effort to maximize the cleansing of the instrumented canal walls, although perhaps not universally recommended.

It can be argued that the use of 2.0 mL saline as a final rinse was not necessary, at least not for this study. However, the authors believe that this was an important step to rid the canal of chemicals that had been previously used. To eliminate variables, equal volumes of irrigants were used for all teeth. A potential variable that may have affected the results for all groups is that the use of irrigants appeared to be less effective in areas that were not or partially instrumented.

Although the time required to prepare the root canals in each group was not recorded, it was our impression that the AET technique was simpler and less time-consuming, followed by ProFile and manual instrumentation.

Conclusions

Although better instrumentation scores were obtained in canals prepared with AET, complete cleanliness was not achieved by any of the techniques and instruments investigated.

Whether this translates into a clinically more successful treatment cannot be determined from this study. Within the limitations of this study, however,

the use of AET is promising and warrants further laboratory experiments and clinical trials.

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